

# APPENDIX A

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## Process and apparatus for workpiece coating

The present invention relates to a coating arrangement according to the generic specification of claim 1 as well as a process for coating workpieces according to the generic specification of claim 14.

In many known vacuum treatment processes, cleaning of the workpiece surface is performed prior to vacuum coating. In addition, the workpieces may be heated to the desired temperature before or after the cleaning step. Such steps are principally needed to ensure adequate bonding strength of the coating to be deposited. This is especially important in applications where workpieces, and tools in particular, are to be coated with a wear protection coating. On tools such as drills, milling cutters, broaches and shaping dies such coatings are subjected to very high mechanical and abrasive stress. An extremely good bond with the substrate is, therefore, essential for useful and economical use. A proven method for pre-treating such tools is heating with electron bombardment, and etching by means of ion etching, for example, sputter etching. Heating by means of electron bombardment from a plasma discharge is known, for example, from DE 33 30 144.

A plasma discharge path can also be used for creating heavy noble gas ions, for example, argon ions, which are accelerated from this plasma toward the workpiece or the substrate on which they cause sputter etching as described in DE 28 23 876.

In addition to sputter etching another known technique is to operate plasma discharges with additional reactive gases and to etch the workpieces chemically, however, also process techniques combining reactive etching and sputter etching are feasible. The objective of all these pre-treatment processes is to prepare the workpiece surface in such a way that the subsequently deposited coating adheres well to the substrate.

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For plasma generation the aforementioned arrangements use a low-voltage arc discharge that is arranged in the central axis of the apparatus whereas the workpieces are arranged at a certain distance around this arc along a cylindrical surface. The coating is subsequently deposited by means of thermal evaporation or sputtering. Depending on the process management, an additional ion bombardment is generated during the coating through a corresponding substrate bias, a technique which is known as ion plating. The advantage of this arrangement is that large ion currents with small particle energy can be drawn from the low-voltage arc which affords gentle treatment of the workpiece. The disadvantage is, however, that the workpieces must be arranged in a zone defined radially to the discharge and that as a rule they must be rotated round the central axis as well as their own axis in order to achieve uniform and reproducible results.

Another disadvantage is that due to the relatively narrow admissible cylindrical processing band width either the processable workpiece size is limited or the batch size is limited for a large number of small workpieces which severely limits the cost-effectiveness of the known arrangements. This limitation is due to the fact that the low-voltage arc discharge which centrally penetrates the process chamber requires a certain dimension for itself. In order to produce good and reproducible results, the workpieces must have a suitable distance from the discharge which means that a large portion of the central process chamber space cannot be utilized.

Also known are sputtering arrangements with so-called diode discharges. Such diode discharges are operated with high voltages of up to 1000 Volt and even higher. Diode etching devices have proven to be unsuited to applications with demanding requirements. On the one hand the achievable etching rates and consequently the efficiency is low, and on the other hand these high voltages can produce defects on sensitive substrates. In particular workpieces that require three-dimensional processing such as tools cannot be readily processed by such an arrangement. Tools, for example, are

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designed with a number of fine cutting edges on which such discharges tend to concentrate, with the result that uncontrolled effects such as overheating and even destruction of the functional edge can occur on such fine edges and points.

In the patent application DE 41 25 365 an approach for solving the aforementioned problem is described. It assumes that the coating is deposited by means of a so-called arc evaporation process. In order to produce well-bonding coatings with such evaporators, the arc of the evaporator itself was used prior to the actual coating in such a way that the ions produced in the arc, particularly the metal ions, are accelerated out of the evaporation target toward the workpieces by means of a negative acceleration voltage of typically > 500 Volt, but often also in the range of 800 to 1000 volt so that more material is sputtered off the workpiece than deposited. After this etching process the evaporator is operated as a coating source. The description mentions that in the usual processes based on the arc coating technology such high voltages are essential for producing well-adhering coatings through the arc evaporation process.

To prevent the problem of overheating or etching on uneven mass distribution or on fine workpiece geometries, the description proposes to operate, in addition to the arc plasma, an auxiliary discharge path with high voltage that causes supplementary ionization which is coupled to the evaporation arc. An additional DC source causes ions to be extracted from the plasma and accelerated to the workpiece and thereby produce the desired etching effect. An additional anode with another discharge path operated from a separate power supply is envisioned for increasing the effect. During the etching process the arc evaporator is operated with a closed shutter so that the substrate is shielded from the direct effect of the evaporator, thereby preventing so-called droplets on the substrate.

The disadvantage of the above arrangement is that it also requires a high voltage, that only limited processing homo-

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geneities are achievable, and that through the coupling of the different plasma paths also the adjustment capabilities in the operating environments are limited. In addition this arrangement is very complicated and consequently costly to build and operate which seriously impairs the economy of a production system. The utilization of voltages in excess of 1000 Volt requires additional safety precautions.

Systems that are based on the current technology are not well suited to high throughputs if also high processing quality is required. Systems that accommodate coating widths of up to 1000 mm and more can be built only with great difficulty, if at all.

The purpose of the present invention is to eliminate the aforementioned disadvantages of the current technology, in particular by creating a coating arrangement and by proposing a process that is suitable for depositing well-adhering coatings on a large number of workpieces, or on individual large workpieces with uneven mass distribution, without damaging the fine structures but with the desired homogeneity and the required highly economical processing rate.

This is achieved by designing the process arrangement mentioned at the beginning in accordance with the characterizing portion of claim 1, and by the coating process designed according to the characterizing portion of claim 14.

Accordingly the workpiece surface to be coated is exposed to a plasma source designed as a hot cathode low-voltage arc discharge arrangement by transporting it transversely to the linear extent of the latter's discharge path. The workpiece is connected to a negative voltage so that ions are extracted from the arc discharge and accelerated to the workpiece, causing the latter to be sputter etched. Subsequently the workpiece is coated from the same side from which the low-voltage arc discharge was effective.

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The preferred design variants of the coating arrangement conforming to the invention are described in the subsidiary claims 2 to 13, and the preferred design variants of the process in claims 14 to 17.

Etching with a hot cathode low-voltage arc discharge arrangement as the ion source is particularly advantageous because such arc discharges can be operated with discharge voltages of < 200 Volt which means that this process is not afflicted by the disadvantages of high-voltage etching. Etching with low-voltage arc discharges is also particularly harmless to the workpiece, that is, the fine structures on larger workpieces such as cutting edges are adversely affected neither by thermal overload nor edge rounding caused by high-energy ion bombardment.

Despite the relatively low discharge voltage in the working range of 30 to 200 Volt DC, but preferably within the range of 30 to 120 Volt, a very high discharge current of a few 10 to a few 100 ampere, preferably from 100 to 300 ampere, is feasible. This means that this type of discharge is able to produce a very high ion current at low energy. Due to the high ion current available, a high etching rate can be achieved on the substrate at a relatively low acceleration voltage, and as has been mentioned before, with gentle treatment of the workpiece. The extraction voltage or the acceleration voltage on the substrate is within the range of -50 Volt to -300 Volt, preferably within the range of -100 Volt to -200 Volt. The ion current drawn to the workpieces achieves values of 5 to 20 ampere, with a preferred working range from 8 to 16 ampere. The processing width for the workpiece or workpieces can be up to 1000 mm. With a somewhat more elaborate equipment design also larger processing widths are feasible. The achievable values depend not only on the operating values for the arc discharge but also on their geometric arrangement relative to the workpiece, as well as on the selected working pressure. Typical working pressures are of the order of  $10^{-3}$  mbar. For operating th

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arc discharge a noble gas is used as the working gas, preferably a heavy noble gas such as argon.

In the past, low-voltage arc discharge arrangements were rotation symmetrical which means that the arc discharge was arranged in the center and the workpieces were rotated around this arc discharge located in the central axis. The assumption was that the rotation symmetrical arrangement with the centrally arranged arc discharge would offer the best possible result with respect to uniformity and speed of the etching operation. Surprisingly it has been shown, however, that the asymmetrical arrangement proposed by the invention is overall much more advantageous than the aforementioned rotation symmetrical arrangement. With a rotation symmetrical arrangement with the arc discharge in the central axis the placement of large volume workpieces is restricted toward the center by the arc discharge itself. In addition such workpieces have to be rotated not only around the central axis but also around their own axis so that after the etching process the etched workpiece surfaces can be coated immediately with the coating sources arranged on the chamber wall. Only in this way is adequate distribution of the etching process and the coating thickness ensured.

It has also been shown that the distance of the workpiece from the arc discharge is more critical in a rotation symmetrical arrangement than in an asymmetrical arrangement in which the workpiece is exposed only from one side toward the arc discharge.

In the apparatus according to the invention it is possible to pass large-volume workpieces in front of the arc discharge without additional rotation, with the result that the size of the process chamber can be kept within reasonable limits and the handling of heavy workpieces is greatly simplified. This has a significant influence on the economy of production systems. The arrangement according to the invention is advantageous not only for large-volume workpieces but it is also possible to accommodate and simultaneously

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process a correspondingly large number of smaller workpieces.

Another advantage of the arrangement according to the invention is that the etching apparatus no longer has to be constructed as an integral part of the process chamber because it needs to be arranged only in the area of the process chamber wall which means that it can be arranged as an elongated, smaller discharge chamber on the latter's outer wall so that far greater freedom is achieved in the design of the process chamber. It has even been found that this arrangement is far less critical with respect to the distance between the arc discharge and the workpiece surface, which means that higher reproducibility of the results is achieved with larger spacing variations that typically occur with larger workpieces. The total ion current that can be extracted from the arc discharge still reaches advantageously high values and can be concentrated fully on the workpieces, thereby producing the desired high etching rates. The actual separation of the low-voltage arc discharge or the plasma source from the process chamber or from the treatment zone also affords a higher degree of freedom in the design of this source and consequently a much more flexible adaptation of the source design to the process requirements than is the case with the integral rotation-symmetrical arrangement with discharge in the central axis of the equipment.

For depositing a well-bonding coating after the etching process, one or more additional evaporation sources acting from the same side are arranged on the process chamber wall. Particularly suited are sources that can be arranged in such a way that, like the elongated low-voltage discharge, they coat the workpieces transported in front of them across a correspondingly elongated area. Suited are sources such as sputtering sources or arc evaporation sources. Practice has shown that so-called cathodic spark evaporators or arc evaporators are particularly suited because well-bonding coatings can be economically produced by these and the preceding etching process. Test tools processed through this

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arrangement achieved a useful life that was significantly and reproducibly longer than achieved by known arc evaporated coatings with preceding high-voltage etching. For example, the useful life of cutting tools such as milling cutters was improved by a factor of at least 1.5; in particularly favorable cases even by a multiple over conventional techniques. In addition a very homogenous etch distribution was achieved which is far less dependent on the workpiece geometry and also allows mixing of different substrates in a batch.

With the proposed arrangement it is also easily possible to implement processes not only with noble gases but also with chemically active gases because the low-voltage arc discharge activates gases such as  $N_2$ ,  $H_2$  very well. Unwanted parasitic discharges produced by insulating surfaces can be easily controlled with the low-voltage discharge. The low-voltage arc discharge is preferably operated with a separate cathode chamber or ionization chamber that accommodates a hot cathode and communicates with the discharge chamber or the process chamber only through a small opening. The gases are preferably admitted via this cathode chamber. This results in a certain gas separation between the process chamber and the coating sources which reduces or eliminates the problem of target contamination. With this arrangement it is also possible to perform activation on the workpiece with different process gases during the actual coating phase. The desired working conditions can be established by choosing a corresponding negative or even positive voltage on the workpiece.

As the workpieces generally have to be passed in front of the sources several times during a process step in order to achieve the necessary etching depth or coating thickness as well as uniform and reproducible treatment, it is advantageous to design the apparatus in such a way that the workpieces can be rotated around a central axis and to arrange the sources on the chamber wall in such a way that they all work from the outside toward the inside. In this case a very

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large workpiece can be arranged for processing in such a way that it rotates on its central axis. In the same space, however, also a large number of small workpieces, even of different size, can be arranged on a holder and passed across the sources while rotating around this central axis in order to achieve homogenous results. Such an arrangement is particularly compact and easy to build which is essential for an economical process.

The plasma source or the low-voltage arc discharge is preferably arranged on the process chamber wall, transversely to the transport direction. The low-voltage arc discharge device can, for example, and preferably be arranged in a box-like attachment, here in the form of a discharge chamber, which is connected to the process chamber by a long narrow opening in such a way that the low-voltage arc is arranged directly opposite the workpiece(s) or the zone to be processed. The low-voltage arc discharge is generated by an electrically heated or thermionic emission cathode and an anode arranged at a certain distance. A corresponding discharge voltage is applied to this anode, causing an arc current to be drawn. This discharge features a gas inlet port through which the arc discharge is supplied with the working gas. This arrangement is preferably operated with a noble gas such as argon, but as has been mentioned above, also reactive gases can be added. The size of the discharge path should be at least 80% of the treatment zone width and be positioned relative to the treatment zone in such a way that the desired treatment distribution or homogeneity can be attained. To achieve the corresponding sputter etching on the workpiece, the latter or the workpiece holder is operated with a negative voltage relative to the arc discharge arrangement. Depending on the process, such as in reactive processes during the coating, the arrangement can also be operated without such a voltage or even with a positive voltage, that is, with electron bombardment. Aside from a DC voltage also a medium or high-frequency AC voltage can be used, and also superposition of DC on AC is feasible. The DC voltage can also be pulsating, and it is possible to super-

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pose only part thereof on the AC supply. With such a supply it is possible to control certain reactive processes. It also can in particular avoid or prevent parasitic arcs if dielectric zones exist or are formed on the equipment and the workpiece surfaces.

The desired distribution with respect to the processing zone can be set via the length of the discharge and its location. Another parameter for controlling the distribution is the plasma density distribution along the arc discharge. This distribution can e.g. be influenced with the aid of additional magnetic fields which are arranged in the area of the discharge chamber. For the setting and correction of the process parameters, permanent magnets are positioned along the discharge chamber. Better results are achieved, however, if the discharge path is operated with additional, separately powered anodes which are arranged along the discharge path in accordance with the distribution requirements. With such an arrangement even the distribution curve can be influenced to a certain degree. Preferred is, therefore, the arrangement without correction magnets and with more than one anode along the discharge path. However, it is also possible to combine this preferred arrangement with additional correction magnets. Additional anodes can be readily operated in combination with a single cathode. It is advantageous, however, to have an emission cathode opposite each anode in order to achieve optimum decoupling of these circuits which in turn improves the controllability.

The thermionic emission cathode is preferably arranged in a separate, small cathode chamber which communicates with the discharge chamber through a small opening. This cathode chamber is preferably equipped with an inlet port for noble gas. If desired also reactive gases can be admitted via this gas inlet. Preferably, reactive gases are not admitted into the cathode chamber but, for example, into the discharge chamber. Through the opening in the cathode chamber the electrons are drawn to the anode or anodes so that the gas which is at least partially ionized also emerges from this

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opening. The process chamber is preferably designed in such a way that the central axis around which the workpieces are rotating, is arranged vertically. The cathode or the cathode chamber is preferably arranged above the anode. In the cathode chamber the exit opening is preferably arranged downward. These arrangements simplify the entire handling of the system and help to avoid problems that can be caused by particle formation.

In addition to the low-voltage arc discharge arrangement the process chamber is equipped with at least one additional source, preferably in the form of an arc evaporator. These sources act radially in the same direction from the outside toward the central axis or the processing zone. It is advantageous if the low-voltage arc discharge is arranged before the coating source with respect to the transport direction. An arc evaporator, like the arc discharge arrangement, usually has a linear extent that is transverse to the transport direction so that the entire processing zone can be coated with the desired homogeneity. In the proposed coating arrangement several round arc evaporators are preferably used which are distributed along the chamber wall in such a way that the desired homogeneity is achieved. The advantage is that the high power consumption of the evaporator can be split up and that coating thickness distribution can be better controlled or to a certain degree be even adjusted by means of the power supply. In this way exceptionally high coating rates can be achieved which results in high economy. For example, a process for tools, particularly shaping dies, would be configured as follows:

#### Process example

The system configuration corresponds to illustrations 2 and 3. The tools are not rotated around their own axis but only pass d in front of the sources by rotating the workpiece holder around its central axis. A coating zone with a width b of 1000 mm and a diameter d of 700 mm is formed, within which the workpieces are arranged. The process chamber has a diameter of 1200 mm and a height of 1300 mm.

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**Etching parameters:**

Low-voltage arc current	ILVA = 200 A
Arc discharge voltage	ULVA = 50 V
Argon pressure	P <sub>Ar</sub> = $2.0 \times 10^{-3}$ mbar
Etching current	I <sub>sub</sub> = 12A
Etching time	t = 30 min
Etching depth	200 nm

**Coating:**

Current for each arc evaporator	IARC = 200 A
(8 evaporators with 150 mm diam. titanium targets)	
Arc discharge voltage	UARC = 20 V
Nitrogen pressure	P <sub>N2</sub> = $1.0 \times 10^{-2}$ mbar
Bias pressure	U <sub>Bias</sub> = -100 V
Coating time	t = 45 min
Coating thickness TiN	6 μm

The process cycle time for one batch, including heating and cooling, is 150 min.

The voltage generation equipment for the negative acceleration voltage on the workpiece is usually operated with voltages of up to 300 Volt DC, but to protect the workpieces the voltage is preferably kept within the range of 100 to 220 Volt at which good etching rates are still feasible without defects. The low-voltage arc arrangement must be operated at least 10 cm away from the workpiece, but the distance should preferably be > 15 cm, or preferably within the range of 15 to 25 cm at which high rates with a good distribution are achieved.

The coating system according to this invention is particularly suitable for processing tools such as drills, milling cutters and shaping dies. The holders and the transport device are designed specifically for this type of tools. The present coating arrangement is generally able to achieve good results even if the workpieces to be coated are rotated only around the central axis of the equipment. In particu-

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larly critical cases or if a very large number of small parts are to be loaded into the system, the rotation around the central axis can easily be supplemented in this design concept by adding additional rotating axes which in turn rotate around the central axis.

The invention is subsequently exemplified and schematically explained by means of the following illustrations:

- Fig. 1 A coating arrangement with low-voltage discharge according to the conventional technology. (State of the art).
- Fig. 2 Cross-section of a typical coating system according to the invention, with peripheral discharge chamber for low-voltage discharge
- Fig. 3 Horizontal section of the system illustrated in Fig. 2.
- Fig. 4a Cross-section of a part of the arrangement with discharge chamber for low-voltage arc discharge and multiple anodes arranged inside the chamber.
- Fig. 4b Same as Fig. 4a but illustrated with separate cathode-anode discharge paths with the cathodes arranged in separate cathode chambers.
- Fig. 4c Same as Figs. 4a and 4b, also with separate cathode-anode discharge paths, but with the cathodes arranged in a common cathode chamber.
- Fig. 5 Service life comparison curves for tools coated with the conventional technology and the technology according to the present invention.
- Fig. 1 illustrates a known workpiece coating arrangement. A vacuum chamber serves as process chamber 1 for accommodating a low-voltage arc discharge 18 which runs in the center of

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vacuum chamber 1 along the latter's central axis 16 and to which magnetron sputtering sources 14 are flanged at the periphery from the outside to the chamber wall of process chamber 1. On the top of process chamber 1 there is a cathode chamber 2 that holds a thermionic hot cathode 3 which can be supplied via gas inlet 5 with the working gas, typically a noble gas like argon. For reactive processes also active gases can be added. Cathode chamber 2 communicates with process chamber 1 via a small hole in shutter 4. The cathode chamber is usually insulated from processing chamber by means of insulators 6. Shutter 4 is additionally insulated from the cathode chamber via insulator 6 so that shutter 4 can be operated on floating potential or auxiliary potential, as required. Anode 7 is arranged in the direction of the central axis 16 on the opposite side of cathode chamber 2. Anode 7 can have the form of a crucible and holds the material to be evaporated by the low-voltage arc discharge. During the etching process this evaporation option is not used; only ions are extracted from the low-voltage arc discharge and accelerated toward the workpieces in such a way that the latter are sputter etched. For operating the low-voltage arc discharge 18 cathode 3 is heated with a heater supply unit so that cathode 3 emits electrons. Between cathode 3 and anode 7 there is an additional power supply 8 for operating the arc discharge. It usually produces a positive DC voltage on anode 7 in order to sustain the low-voltage arc 18. Between arc discharge 18 and the chamber wall of processing chamber 1, workpiece holders are arranged that hold the workpieces 11 which can be rotated around their vertical central axis 17 in order to achieve adequate process uniformity. The workpiece holders 10 are supported on an additional workpiece holder arrangement 12 which is equipped with a rotary drive by which these workpiece holders 10 are rotated around the central axis 16. In this type of equipment it is additionally necessary to focus the low-voltage arc discharge 18 via additional coils 13, for example in the form of Helmholtz coils. It is evident that the workpieces 11 can be processed with the low-voltage arc discharge 18, that ion bombardment occurs when a gas-

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tive voltage is applied to the substrate, and that electron bombardment is possible by applying a positive substrate voltage. In this way the workpieces can be pre-treated with the aid of a low-voltage arc discharge either by means of electron bombardment induced by heating, or through ion bombardment with sputter etching. Subsequently the workpiece 11 can be coated, either through evaporation of material from crucible 7 by means of the low-voltage arc, or through sputtering with magnetron sputter source 14 which is supplied by the power supply 15.

It is readily apparent that the mechanical assembly for substrate movement and the arrangement of the low-voltage arc discharge are rather complex in this layout. On the other hand the degree of freedom is severely restricted because the workpieces can only be arranged between the low-voltage arc discharge located in the center and the outer chamber wall. A system of this type is uneconomical to operate for large workpieces or large batch quantities.

An example of a preferred coating arrangement according to the invention is illustrated as a cross-section in Fig. 2. Process chamber 1 contains a workpiece holder 11 which is arranged in such a way that the workpieces can be rotated around the central axis 16 of the process chamber. The chamber is usually pumped down by the vacuum pumps 19 that maintain the working pressures required for the process steps. In the proposed arrangement a large workpiece 11 which extends beyond the central axis 16 can, for example, be arranged in process chamber 1 in such a way that this large workpiece 11 can be processed by the sources arranged on the process chamber wall. The zone available for loading the workpieces essentially fills process chamber 1 completely. In such an arrangement it is possible to position either a single large workpiece 11 or a large number of smaller workpieces which essentially fill the chamber volume.

The workpiece holder that rotates the workpieces 11 around the central axis 16, spans coating width transversely to

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the rotation direction. In the system according to the invention it is particularly advantageous that uniform and reproducible coating results can be achieved either across large coating widths  $b$  or across a large depth range that extends from the central axis 16 to the periphery of the coating width, that is, within the entire diameter  $D$ . Based on the known concentric arrangement according to the conventional technology in which these conditions were critical, it was not to be expected that an eccentric arrangement according to the present invention would produce better results. A large variety of workpiece geometries with fine edges and cutting edges can be handled in this large area without problems related to thermal stress or unwanted occurrence of arcs.

On the outer wall of the process chamber the etching and coating sources are positioned in such a way that they all act from the outside toward the workpieces. For the important preparatory sputter etching process the chamber wall features a slot shaped opening, the length of which corresponds at least to processing width  $b$ . Behind this opening 26 there is a box shaped discharge chamber 21 in which the low-voltage arc discharge 18 is generated. This low-voltage arc discharge 18 runs essentially parallel to processing width  $b$  and has an effective length which shall be at least 80% of processing width  $b$ . Preferably the discharge length should be equal to the processing width  $b$  or extend even beyond it.

The axis of arc discharge 18 has a distance  $d$  from the nearest processing zone, that is, the next workpiece section. This distance  $d$  shall be at least 10 cm, preferably 15 to 25 cm. This results in good process uniformity and a high sputtering rate can be maintained. In the lower part of discharge chamber 21, cathode chamber 2 is flanged on which communicates with discharge chamber 21 via orifice 4. Cathode chamber 2 contains a hot cathode 3 which is supplied with heating power supply unit 9. This supply can be operated with AC or DC. Cathode chamber 2 features a gas inlet port 5 for supplying the working gas, normally a noble gas like

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argon, or a noble gas - active gas mixture for certain reactive processes. It is also possible to admit working gases via process chamber 1 by means of auxiliary gas inlet 22. Active gases are preferably admitted directly into process chamber 1 via gas inlet 22.

In the upper part of discharge chamber 21 there is an electrode 7 which is designed as a anode. DC supply 8 is connected between cathode 3 and anode 7 in such a way that the positive pole is on anode 7 and a low-voltage arc discharge can be drawn. By applying a negative voltage to the workpiece holder or to the workpieces 11 with the aid of voltage generator 20 between the low-voltage arc discharge arrangement and the workpiece 11, argon ions are accelerated toward the workpieces so that the surface is sputter etched. This can be achieved with acceleration voltages of up to 300 Volt DC, but preferably with a voltage in the range of 100 Volt to 200 Volt to ensure gentle processing of the workpieces 11. The process uniformity can be set through appropriate positioning of cathode chamber 2, and by arranging anode 7 relative to processing width b of the workpieces to be processed in accordance with the process specifications. Another factor is the shape of anode 7. The latter can, for example, have either a flat, dished, or rectangular shape, or be designed as a tubular, cooled anode.

Fig. 3 shows a horizontal cross-section of the system based on Fig. 2. Shown is again the box-like discharge chamber 21 on the outer wall of process chamber 1 which communicates with the treatment zone through slot opening 26. Of course, several such discharge chambers can be arranged on a system as required, for example to further boost the processing effect. Also illustrated are the evaporation sources 23 which are flanged to the chamber wall. For example, magnetron sputter sources can be used as evaporation sources 23 but for achieving high processing speeds at low costs, so-called arc evaporation sources are preferably used. The advantage of this arrangement is that the arc evaporation sources 23 can be freely arranged from the outside in such a

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way that through the distributed arrangement of multiple sources the desired coating homogeneity can be set and a high coating rate can be maintained. It has been shown that it is more advantageous not to use single, rectangular evaporation sources but several smaller, round sources that are arranged on the periphery of the system in accordance with the process requirements.

Fig. 4a illustrates another advantageous variant of the arrangement according to the invention in which cathode chamber 2 is located on the top of discharge chamber 21. The advantage is that the operating of the discharge path is least disturbed by particles which always occur in such a coating system. Also shown is a the possibility of subdividing the discharge path by using several anode-cathode circuits and making the intensity along discharge 1 adjustable. The main discharge is generated with power supply 8 between main anode 7 and cathode chamber 2. Additional ancillary discharges can be generated with auxiliary anodes 24 and auxiliary power supplies 25. In this way it is possible to adjust the power density of the discharge along the entire discharge path between anode 7 and cathode 2 locally and with respect to the intensity to the homogeneity requirements of the workpiece.

Fig. 4b shows an alternative arrangement. The anode-cathode paths can be kept completely apart, or even decoupled by using separate anodes 7, 24, separate cathodes 3, 3', and separate cathode chambers 2, 2'. Another version is illustrated in Fig. 4c in which two separate anodes 7, 24 are used, but a common cathode chamber 2 with two hot cathodes 3 and 3'.

Fig. 5 illustrates the test results of HSS finish milling cutters that were processed according to the invention (curve b) and the conventional technology (curve a). In both cases the milling cutters were given a 3.5  $\mu\text{m}$  TiN coating. For the milling cutter according to the conventional technology (curve a) high-voltage etching was first performed in

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the conventional manner whereas for the milling cutter represented by curve b the process according to the invention was used. The test conditions were as follows:

HSS finish milling cutter:	Diam. 16 mm
Number of teeth:	4
Test material:	42 CrMo4 (DIN 1.7225)
Hardness:	HRC 38.5
Infeed:	15 mm x 2.5 mm
Cutting speed	40 m/min
Feed per tooth	0.088 mm
Feed	280 mm/min

End of life: Spindle torque 80 (arbitrary unit)

The result shows clear improvements in the life of the tool treated according to the invention. An improvement by a factor of 1.5 or more is easily reached. Important is not only the extension of the tool life but also the flatter progressing of the torque curve which is indicative of the deterioration in tool quality toward the end of the tool life. In the example according to Fig. 5 this is clearly recognizable at a total milling depth of 15 m. Curve a which represents the conventional technology shows a sharp degradation in tool quality at a total milling depth of 15 m. This shows that the cutting quality achievable with the conventional technology has a greater variance across the entire tool life which means that it is not very consistent.

Systems built in accordance with the invention as illustrated in Figures 2 to 4 achieve far greater throughputs with the aforementioned high quality than system 1 which conforms to the conventional technology. Throughputs can easily be doubled or even increased by a factor of 3 to 5 which dramatically increases the economy.

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### Summary

For depositing hard coatings on high-performance tools that must be sputter etched before coating, the invention proposes to sputter etch the tools with a low-voltage arc discharge and to subsequently coat them from the direction they have been etched.

### Patent claims

1. Coating arrangement for treating workpieces (11) with a vacuum process chamber (1) and a plasma source (18) arranged on the chamber, and with a coating source (23) arranged inside said chamber, and said chamber being equipped with a holding and/or transport device which defines a treatment zone (b) for positioning or passing the workpieces (11) in front of the sources, with said sources being arranged at a certain distance to the workpiece and acting from the same direction, characterized by a plasma source (18) designed as a hot cathode low-voltage discharge arrangement, the linear extent (1) of which in a direction transverse to the workpiece transport direction essentially corresponds to width (b) of the processing zone, and containing a device for generating an electrical field (20) between the arc discharge (18) and the workpiece (11).
2. Arrangement according to claim 1 in which the holding and transporting device for the workpieces (11) is arranged rotatable around central axis (16) of process chamber (1) and with sources (18, 23) arranged on the chamber wall in such a way that they all act radially from the outside in the direction of the central axis (16).
3. Arrangement according to claim 1 or 2 in which the plasma source of a discharge chamber (21) is arranged on the outer wall of chamber (1) where inside or in discharge chamber (21) a thermionic emission cathode (3), and at least 80% of the processing zone width away and along processing zone width (b), an anode (7) for generating

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ating a low-voltage arc discharge (18) is positioned and in which arrangement a noble gas port (5) in discharge chamber 21 with a voltage generator (20) is arranged between the anode-cathode circuit and workpiece (11) in such a way that the negative pole is on workpiece (11) so that the plasma source arrangement (2, 7, 18, 21) functions as a sputter etching device.

4. Arrangement according to one of the preceding claims in which at least one additional anode (24) extending along the plasma path at a certain distance from said plasma path is arranged between emission cathode (3) and anode (7) for adjusting the plasma density distribution along arc discharge (18).
5. Arrangement according to one of the preceding claims in which anode (7) and the additional anode (24) are connected to separate, adjustable power supplies (25), and featuring an opposite cathode (3) preferably for each anode (7, 25) which together with the corresponding anode (7, 25) and the separate power supply (8, 25) forms its own adjustable power circuit.
6. Arrangement according to one of the preceding claims in which the emission cathode (3) is arranged in a cathode chamber (2) separate from discharge chamber (21) and with said cathode chamber (2) communicating with the discharge chamber (21) via opening (4) through which the electrons can emerge, with the noble gas inlet port (5) preferably arranged on this cathode chamber (2).
7. Arrangement according to one of the preceding claims 2 to 6 in which process chamber (1) with its central axis (16) is arranged vertically, and cathode (3) or cathode chamber (2) is arranged above the anode (7, 24), and the opening (4) of cathode chamber (2) is preferably pointing downward.
8. Arrangement according to one of the preceding claims in which at least one coating source (23) which preferably consists of at least one arc evaporator (23) is arranged

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on the process chamber wall next to the plasma source (18) which is located further ahead in the transport direction.

9. Arrangement according to one of the preceding claims in which the voltage generator (20) is designed for voltages of up to 300 V DC, preferably for 100 V to 200 V.
10. Arrangement according to one of the preceding claims in which the low-voltage arc discharge arrangement (18) is located at least 10 cm but preferably 15 to 25 cm away from workpiece (11).
11. Arrangement according to one of the preceding claims in which the holding and transport device is designed as a tool holder, particularly for drills, milling cutters and shaping dies.
12. Arrangement according to one of the preceding claims in which at least one magnetic field generator is arranged in or on discharge chamber (21) for adjusting the plasma density distribution.
13. Arrangement according to one of the preceding claims in which discharge chamber (21) has an opening along the full width (b) of the processing zone and with the opening facing the latter so that the processing zone is exposed to the arc discharge.
14. Process for at least partially coating workpieces (11) in a vacuum process chamber (1) with a plasma source (18) arranged on the process chamber and a coating source (23) and with a holding and/or transport device arranged in chamber (1) with said device determining a treatment zone (b) for positioning or passing the workpieces (11) in front of the sources (18, 23), where the sources act from the same side and are arranged at a certain distance from workpiece (11), and in which process the plasma source (18) generates a hot cathode low-voltage arc (18) in a direction transverse to the workpiece transport direction essentially at least across

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80% of width (b) of the treatment zone and in which process a voltage is applied between the arc discharge and the workpiece for extracting charge carriers from the plasma so that they can be accelerated toward the substrate.

15. Process according to claim 14 in which the workpieces rotate preferably continuously around central axis (16) of a processing chamber and pass in front of the sources (18, 23), and in which process the plasma treatment occurs through charge carrier bombardment in a first step and the coating of workpiece (11) in a second step.
16. Process according to claim 14 or 15 in which the charge carriers consist of ions that are extracted from the arc discharge (18) directly with the aid of a negative workpiece voltage in such a way that they sputter etch the workpiece (11).
17. Process according to one of the claims 14 to 16 in which the homogeneity of the etch distribution across coating zone (b) can be set to predetermined values by selecting arc length, the distance (d) between the arc and the workpiece, the position of the arc relative to the workpiece, as well as by adjusting the plasma density distribution along the arc.

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Fig. 5

Spindle torque [a.u]

End of tool life

High-voltage etching + 3.5  $\mu\text{m}$  TiN (arc coating)

Low-voltage arc coating + 3.5  $\mu\text{m}$  TiN (arc coating),

(Invention)

Total milling depth [m]

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